N64-25769
NASA CR-56231

May 27, 1964
Ref: 295/885-21/3678

National Aeronautics and Space Administration
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Washington 25, D. C.

Attention: Dr. Michael Del Duca (Code RB)

Subject: Study of Biochemical Fuel Cells
under Contract No. NASw-654

Enclosure: (1) Fourth Quarterly Engineering Progress Report, "Study of Biochemical Fuel Cells," Report No. 25,136, dated 30 April 1964

1. Enclosure (1) describing the technical results of the work accomplished to date on this program is hereby submitted, in accordance with Article IV, Section B, of the subject contract.

THE MARQUARDT CORPORATION

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THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

Fourth Quarterly Progress Report

1 February 1964 through 30 April 1964

STUDY OF BIOCHEMICAL FUEL CELLS

Contract NASw-654

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ACKNOWLEDGMENT

The assistance and helpful suggestions of Messrs. C. Jerry Adamo, Larry L. Bradford, Thomas Payne, M. Leonard Brown, and Mrs. Betty Hayakawa of this laboratory; and Ernst M. Cohn, Harvey J. Schwartz, John Fuscoe, and Meyer Unger of NASA are hereby gratefully acknowledged.

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I. SUMMARY

The purpose of the investigations described in this report was to continue empirical studies on biochemical fuel cells for degrading human wastes and producing electrical energy therefrom. Specifically, the study includes the attachment of organisms to electrode materials, electrode pretreatment and configuration, the selection of suitable organisms and separator materials, selection of electrolytes and additives, structural materials and control devices, and storage and performance characteristics.

During the fourth quarter, investigations were conducted in pretreating human waste by adding selected microorganisms to sterilized (autoclaved) human wastes. The microorganisms selected were Escherichia coli and Clostridium sporogenes; reaction temperatures were maintained at 75°F or 95-100°F. These organisms were not as effective as indigenous microorganisms in producing electrical power.

The effect of bubbling the fuel-anolyte with inert gas was also evaluated, and it was found to be effective in increasing the anodic open-circuit current density. Bomb calorimetric determinations of the heat of combustion of lyophilized human feces indicated a value of about 4,600 calories per gram.

Platinized platinum alloy screen (90% Pt - 10% Rh) was found to be essentially as effective as platinized platinum foil for these reactions. A reproducibility study indicated that the results of the present experiments are comparable to those obtained in earlier stages of this investigation. The first experiment was conducted in which human waste is being degraded by electrochemical energy.* Results have shown that the cathode (non-biological) reaction is rate determining. Polarographic studies of relatively pure components of human waste are being initiated. Electrical power output from feces (in deionized water) was found to be negligible. Literature surveys are being continued in appropriate areas.

II. INTRODUCTION

This report covers the progress attained during the Fourth Quarter, 1 February 1964 through 30 April 1964, in the Study of Biochemical Fuel Cells, Contract No. NASw-654. The purpose of this program is to conduct empirical studies on biochemical fuel cells for producing electrical energy through degradation of human waste.

*Emphasis will be placed during the duration of this contract on this series of experiments, in which human waste is being degraded by electrochemical energy.

III. DISCUSSION

During the past quarter, investigations have been conducted on the subject contract under the following general topics:

a. Pretreatment of human waste by adding selected microorganisms;

b. Effect of bubbling fuel-anolyte with inert gas;

c. Bomb calorimetric studies of the heat of combustion of lyophilized, human feces;

d. Effect of electrode metal;

e. Reproducibility study;

f. Effect of imposing a sustained electrical current on the biofuel cell, to degrade the waste;

g. Determination of whether the anode or cathode reaction is rate limiting;

h. Polarographic studies; and

i. Continuations of the literature surveys associated with these studies.

During this contract, attempts have been made to eliminate variables, wherever possible, and to concentrate upon the reactions in the anodic half-cell. For that reason, the experimental conditions outlined in Table I of the Appendix apply throughout this report, unless otherwise specified.

A. Pretreatment of Human Waste by Adding Selected Microorganisms

Two experiments were conducted to determine the electrochemical activity of human waste mixtures to which selected microorganisms had been added.

The conditions of the experiments were essentially the same as those outlined for the non-flow system in Table I of the Appendix, except that the feces-urine mixture was sterilized of indigenous microorganisms, by autoclaving at 250°F for 20 minutes.

In one experiment, 1% of a culture of Escherichia coli in nutrient broth was added to the sterile feces-urine fuel-anolyte mixture. Two cells were thus assembled, one maintained at room temperature (approximately 75°F) and the other incubated at 95-100°F (essentially body temperature).

During the first 85 hours of this experiment, the anodic open-circuit potentials of the two cells were essentially the same. After that time the anodic open-circuit potential of the cell maintained at room temperature was 150 to 250 millivolts better than that of the incubated system. The total time of the experiment was 350 hours. Polarization and power data for this experiment (No. 57) are summarized in Table IV of the Appendix.

In another experiment, conducted in a manner similar to that described above, a 1% culture of Clostridium sporogenes in nutrient broth was added to the sterilized fuel-anolyte instead of the E. coli. Again, two cells were assembled; one was maintained at room temperature (75°F) and the other was incubated (95-100°F).

The anodic open-circuit potential of the incubated cell was approximately 250 millivolts better than that of the cell at room temperature for the period from 15 to 57 hours, then they became essentially the same for the next 94 hours. Polarization and power data for this experiment (No. 58) are summarized in Table IV of the Appendix.

On the basis of these experiments, there seems to be no significant effect of raising the reaction temperature from room temperature to a standard incubation temperature, and these microbes were not as effective as indigenous microorganisms in producing electrical power.

B. Effect of Bubbling Fuel-Anolyte with Inert Gas

An experiment was conducted to determine the effect of bubbling the fuel-anolyte mixture with inert gas (helium), to provide agitation and remove gaseous products; the gaseous products may be either inhibitory or enhancing to biofuel cell reactions.

The conditions of the experiment were essentially the same as those described for the non-flow system in Table I of the Appendix, except that two cells were assembled. The fuel-anolyte of one cell was bubbled with helium, as is customary, while that of the second cell was not bubbled with gas. Agitation was provided for the second cell by means of a mechanical shaker; the second cell was maintained gas tight to avoid loss of gaseous products. Data were obtained at various times during the experiment, and a summary is presented in Table IV of the Appendix. (Run 59)

It is apparent that bubbling the fuel-anolyte is advantageous, in contrast to mechanical agitation, because both the best anodic open-circuit potential and the short-circuit current density are better for the bubbled system. This indicates that some inhibitory substances are being removed from the cell by bubbling, and that the agitation provided by bubbling is sufficient to minimize polarization.

C. Bomb Calorimetric Studies of the Heat of Combustion of Lyophilized, Human Feces

Samples of previously frozen human feces, obtained from volunteers on a low-cellulose diet, were lyophilized. Two of these samples were then combusted in an oxygen bomb calorimeter, and the gross heat of combustion was found to be 4591 and 4697 calories per gram. A summary of the data is presented in Table II of the Appendix.

It may be noted that these values are higher than some values that have been calculated and reported in the literature, based upon estimated compositions of human feces and the heats of combustion of the components.

D. Effect of Electrode Metal

One of the objectives of this study is to evaluate electrode materials. This phase of the program has been held in abeyance, to permit emphasis on more fundamental aspects of the problem.

However, noble metal screen (90% Pt - 10% Rh) is available for fabricating electrodes, and a measurement was made of the potentials obtainable with this platinized metal as compared to platinized platinum foil. It was found that the anodic open-circuit potential of platinum foil in the non-flow system was approximately 0.1 volt higher than that of the platinized Pt-Rh screen, even though the fuel-anolyte in the two systems was obtained from the same mixture.

The test was repeated, using platinized platinum foil in both the flow and non-flow systems, and using portions of a single fuel-anolyte mixture. Again, the open-circuit anodic potential was greater in the non-flow system.

It was postulated that a possible explanation for this difference in potentials might be found in the methods of introducing gases to the electrodes. An experiment was conducted to determine the magnitude of this effect.

In this experiment, four cells were assembled and run simultaneously. One was a plastic cell in a flow system. The other three were H-cells (non-flow) that differed in the following respects: (a) Gas bubblers were placed below the electrodes, as customary; (b) gas bubblers were placed above the electrodes; and (c) gas bubblers were placed below the bubblers as usual, but only the supernatant liquid of a feces-urine mixture was used as the fuel-anolyte. The experimental conditions were the same as those described in Table I of the Appendix, except that foil electrodes were used in the flow system, and the catholyte contained 2-1/2 weight percent NaCl and 2-1/2 percent KCl.

These cells provided a method of determining whether the difference in potentials obtained with the flow and non-flow systems (both employing plastic foil electrodes) could be caused by the lack of contact of the anode in the flow system with solid feces, or whether the inclusion of bubbles of gas in the electrolyte (e.g., oxygen) might be effective in increasing the electromotive potential in the H-cell.

The results are summarized in Table IV (Experiment 65), and it is apparent that the peak anodic power density was not improved by bubbling the gases directly into the plastic cell (compare the data of Experiment 65 of this report with Experiment 1, Table IV-A, of the Second Quarterly Report). However, it was found that the open-circuit anodic potential of the flow system exceeded that of the normal H-cell for a period of time (see Figure 1). The reason for the delay in attaining an open-circuit potential of approximately 500 millivolts in the plastic cell, as well as the reason for the potential of the normal H-cell ultimately exceeding that of the plastic cell, have not yet been determined but are doubtless due to microbiological reactions.

The data of Experiment 65 further showed that placing the gas bubblers below the electrodes, as has been done in most of these experiments, is more effective for agitation but does not cause any higher cathodic potential than if the bubbler is above the electrode so that it merely saturates the electrolyte but does not bubble gases across the electrode. The data also showed that the supernatant fuel-anolyte mixture containing no solids is essentially as effective as the fuel-anolyte containing solids.

E. Reproducibility Study

A standard reproducibility run was made with the non-flow, H-cell system. The experimental conditions were the same as those described in Table I of the Appendix. The statistical data from the experiment were satisfactory.

Three cells were used, and the statistical data covering the first 27 hours of the experiment are tabulated below:

	This Experiment	Previous Experiments
Mean of Maximum Differences of Potentials (volt)	0.038	0.009 - 0.114
Mean Deviation	0.036	---
Variance	0.003	0.000 - 0.004
Standard Deviation	0.056	0.00 - 0.06

In addition to the anodic open-circuit potentials usually obtained in these reproducibility runs, polarization runs were also made and power curves were drawn. The three curves were obtained over a period of 30 hours, so there might be some minor variations in power output due to metabolic activity. However, the data showed that the open-circuit potential remained essentially the same throughout this time period. A summary of the data is presented in Table IV (Experiment 62).

F. Effect of Imposing a Sustained Electrical Current on the Biofuel Cell to Degrade the Waste

A potential of approximately 1.2 volt was imposed in series on the biofuel cell to increase the current flow and the resulting electrochemical reactions occurring over a given time period. The current flow varied from 50 to 70 microamperes, the total time elapsed was 20 days, and the total current was 57.3 coulombs. A control cell was assembled, using a portion of the same fuel-anolyte mixture as that in the cell that had the imposed potential.

It is impractical to make a detailed chemical analysis of the human waste before and after experiment to determine the effect of the imposed potential, because of the complex nature of the material. The most expeditious alternative is to make bomb calorimetric determinations of the heating values, after lyophilization, of feces-urine mixtures from (a) the original sample, (b) the control cell, and (c) the cell subjected to the electrical current. The material has been lyophilized, and the bomb calorimetric determinations will be made during the next month. Bomb calorimetric data will be useful in determining the change in energy content of the fuel, and its resultant state of degradation.

G. Determination of Whether the Anode or Cathode Reaction is Limiting

In the previous experiments the anode and cathode areas have been equal. An experiment has been conducted during the past quarter in which two flow cells were used (in parallel), both having electrodes of unequal areas, to determine which reaction is rate limiting. The electrodes are described below:

Cell I - Anode: Platinized Pt foil, 1 sq. in.; non-opposing faces coated with water repellent paint

Cell I - Cathode: Platinized Pt foil, 2-1/8-in. clear dia., 3.56 sq. in.

Cell II - Anode: Platinized Pt foil, 2-1/8-in. clear dia., 3.56 sq. in.

Cell II - Cathode: Platinized Pt foil, 1 sq. in.; non-opposing faces coated with water repellent paint

In all other respects, the experimental conditions were the same as those described in Table I of the Appendix. A summary of the results is presented in Table IV (Experiment 64).

On the basis of these data, it is apparent that the cathode reaction is limiting, since the use of a larger cathode permits more current to flow, whereas using a smaller anode does not decrease the current flow.

H. Polarographic Studies

A Polarecord E261 polarographic instrument (Metrohm AG Herisau, Schweiz) is being calibrated to be used in obtaining polarographic data on relatively pure solutions of components present in large proportions in urine and feces. This information will be used to determine potentials at which decompositions or other reactions can be expected to occur. This information is necessary and will be employed in the present program of applying potentials to the cells to degrade human waste.

I. Power Output of Feces without Urine

In the past, some experiments were run to determine the effect of feces-urine concentration upon the power output of the biofuel cell. Those concentrations varied from pure urine to a mixture containing 40 grams feces in 100 milliliters urine.

An experiment was run during the past quarter to determine the electrochemical properties of feces without urine. The conditions of the experiment were the same as those for the non-flow system described in Table I of the Appendix, except that deionized, distilled water was used instead of urine. The data indicated that the power output from feces alone was negligible, although it had been found that the feces was effective when added to the urine (see Section III. B. 2. e, Second Quarterly Report).

Cellulase was added to the feces in an effort to decompose the cellulose, but without noticeable effect.

J. Continuation of Literature Surveys

Throughout this program, the literature has been consulted for electrochemical, microbiological, material effects, and other pertinent information and data. These surveys are made concurrently with experimentation.

One item of interest recently has been to obtain the proximate analysis of feces. Fortunately, this information has been found in the literature, and is included in this report as Table III of the Appendix. It will be noted that only approximately 84% of the contents of feces has been identified.

IV. FUTURE WORK

During the next quarter, experiments will be conducted in the following general areas:

1. Bomb calorimetric determinations of the heating value of human waste after various degradation treatments;

2. Use of electrochemical and microbiological reactions to degrade human waste;

3. Determination of limiting current densities of the various reactions;

4. Measurement of physical properties of the fuel-anolyte, including pH, viscosity, density, surface tension, heat capacity, and electrolytic conductivity, at various concentrations and temperatures;

5. Isolation of microbes from human waste, as well as from soil, sewage, etc., to permit development of those bacteria which are most beneficial and can compete most effectively with indigenous microorganisms in waste degradation and electrochemical power generation;

6. Use of non-indigenous microorganisms to further degrade human waste after initial degradation in a biochemical fuel cell;

7. Addition of substances which will enhance microbiological activity in the biofuel cell; and

8. Study of thermophilic microbial activity, similar to composting, for degrading human waste.

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VI. APPENDIX

VARIATION OF OPEN-CIRCUIT POTENTIAL WITH TIME, CAUSED BY METABOLIC REACTIONS

SEPARATOR: CELLULOSE ACETATE

O-RINGS: SILICONE

CATHOLYTE: 2-1/2 wt. % NaCl - 2-1/2% KCl IN STERILE, DEIONIZED WATER; BUBBLED WITH PURIFIED, GASEOUS OXYGEN; NON-BIOLOGICAL

FUEL-ANOLYTE: 30 gms. NON-STERILE, HUMAN FECES (SPECIAL DIET; FROZEN AND THAWED) IN 100 ml. NON-STERILE, HUMAN URINE (FROZEN, THAWED, AND REHEATED TO 120°F). HOMOGENIZED. BUBBLED WITH HELIUM.

ELECTRODES: PLATINIZED Pt FOIL

*FLOW SYSTEM: 2-1/8 in. CLEAR DIAMETER; 3.56 sq. in.

**NON-FLOW SYSTEM: 1 sq. in. AREA; NON-OPPOSING FACES COATED WITH CHEMICALLY RESISTANT, WATERPROOF PAINT

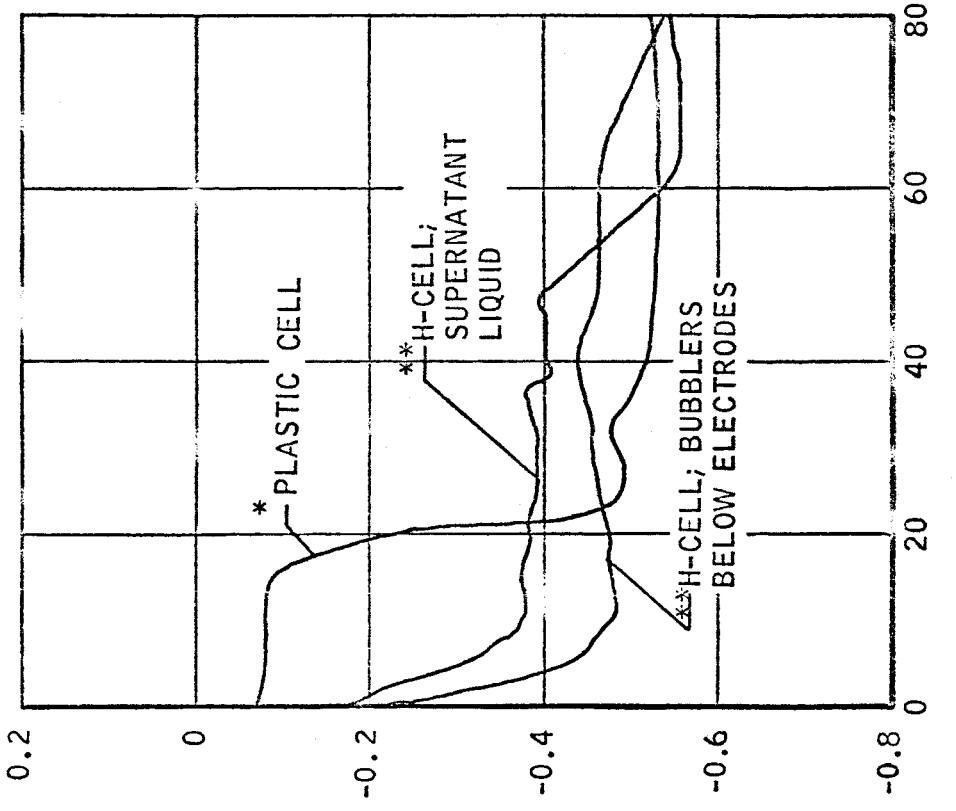

FIGURE 1

TABLE I

EXPERIMENTAL CONDITIONS
BIOCHEMICAL FUEL CELL

FLOW SYSTEM

Cell: Plastic (Lucite)

Electrodes: Platinized screen (90% Pt - 10% Rh), 80 mesh, 0.003 in. diameter wire, 2-1/8 in. clear diameter, 3.54 sq. in. geometric area.

Separator: Cellulose acetate (Sargent S-14825, 0.001 in. thick).

O-Rings: Silicone (Dow Corning S-7180).

Catholyte: 5 wt. % NaCl - 5% KCl in sterile, deionized water; non-biological; bubbled with purified, gaseous oxygen

Waterproof and Chemically Resistant Paint: Temprotec TP 220 Red (Ryan Herco Products Corp., Burbank, Calif.)

Fuel-Anolyte: 30 gms. non-sterile, human urine (frozen and reheated to 120°F). Feces was obtained from volunteers on a low cellulose diet, and was frozen immediately after collection. Homogenized in Osterizer Deluxe (John Oster Mfg. Co., Milwaukee). Bubbled with helium.

NON-FLOW SYSTEM

Cell: Glass, H-Shape, O-Ring type

Electrodes: Platinized platinum foil, 1 sq. in. area (non-opposing faces coated with waterproof and chemically resistant paint).

Separator, O-Rings, Catholyte, Fuel-Anolyte, and Waterproof and Chemically Resistant Paint: Same as for flow system.

TABLE II

CALCULATION OF HEATING VALUE
OF LYOPHILIZED, HUMAN FECES

m = weight of sample (1.0200 gms.; Residue = 0.0803; Consumed = 0.9397 gms.)

t_a = temperature at time of firing: 28.40°C (83.12°F)

t_f = final maximum temperature: 30.20°C (86.36°F)

c_1 = ml of base required for acid titration: 17.00 ml; normality of base used: 0.0725

c_2 = percentage of sulfur in sample: 0.5905%

c_3 = centimeters of fuse wire used: 3.4 cm

w = energy equivalents of calorimeter in calories per degree centigrade: 2415 cal/°C

E_1 = correction in calories for heat formation of nitric acid (HNO_3) (1 cal/ml) = c_1 if .0725 N alkali was used for acid titration: 17.00

E_2 = correction in calories for heat of formation of sulfuric acid (H_2SO_4): (14) (c_2) (m): 7.77 cal

E_3 = correction in calories for heat of combustion of fuse wire 2.3 cal/cm: 8.0 cal

$t = t_f - t_a$ = net temperature rise: 1.80°C

$$H = \frac{t\,w - E_1 - E_2 - E_3}{m} = 4591 \text{ cals./gm.}$$

	Bomb Temp.	Jacket Temp.
Initial Temperature	82.25°F	82.25°F
Final Temperature	86.36°F	86.36°F

TABLE II(Continued)

m = weight of sample (0.9224 gms.; Residue = 0.0758 gms.; Consumed = 0.8466 gms.)

t_a = temperature at time of firing: 26.90°C (80.42°F)

t_f = final maximum temperature: 28.58°C (83.44°F)

c_1 = ml of base required for acid titration: 15.75 ml; normality of base used: 0.0725

c_2 = percentage of sulfur in sample: 0.5808%

c_3 = centimeters of fuse wire used: 4.35 cm

w = energy equivalents of calorimeter in calories per degree centigrade: 2415 cal/°C

E_1 = correction in calories for heat formation of nitric acid (HNO_3) (1 cal/ml) = c_1 if .0725 N alkali was used for acid titration: 15.75

E_2 = correction in calories for heat of formation of sulfuric acid (H_2SO_4): (14) (c_2) (m): 6.88 cal

E_3 = correction in calories for heat of combustion of fuse wire 2.3 cal/cm: 10.0 cal.

$t = t_f - t_a$ = net temperature rise: 1.66°C

$$Hg = \frac{t\,w - E_1 - E_2 - E_3}{m} = 4697 \text{ cals./gm.}$$

	Bomb Temp.	Jacket Temp.
Initial Temperature	80.42°F	80.42°F
Final Temperature	83.44°F	83.44°F

TABLE III

PROXIMATE COMPOSITION OF HUMAN FECES

Component	Weight (gm.)	Per cent of Total
Bulk	150	
Water	99	66.0
Dry Matter	27	17.8
Fat	4.7	3.0
Protein	?	?
Nitrogen	1.5	1.0
Carbohydrate	?	?
Minerals	2.1	1.4
Sodium	0.12	
Potassium	0.47	
Calcium	0.64	
Magnesium	0.20	
Chloride	0.09	
Phosphorus	0.51	
Sulfur	0.13	
Trace Elements:		
Copper		
Iron		
Lead		
Manganese		
Nickel		
Zinc		
Arsenic		
Vitamins	0.015	0.01
Bile Pigments	0.15	0.1

Reference: Goldblith, S.A., and E.L.Wick, "Analysis of Human Fecal Components and Study of Methods for Their Recovery in Space Systems," Dept. of Nutrition, Food Science and Technology, Massachusetts Institute of Technology, Aeronautical Systems Division Tech. Rept. 61-419, Wright-Patterson Air Force Base, Ohio - Aug. 1961

TABLE IV

POLARIZATION AND POWER DATA

Run No.	56	56	56	56	57	57	57
Described in Section	--	--	--	--	III-A	III-A	III-A
Peak Anodic Power Density (mw./sq. ft.)	1.55	3.7	2.0	0.65	0.25	--	--
Peak Total Power Density (mw./sq. ft.)	2.3	4.9	2.2	0.85	0.4	--	--
Short Circuit Current Density (ma./sq. ft.)	38	105	52	13	10	--	--
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.515	-0.523	-0.633	-0.355	-0.175	-0.375	-0.293
Best Anodic Open-Circuit Potential (volt)	-0.585	-0.585	-0.795	-0.795	-0.856	-0.860	-0.860
pH, Initial	7.95	7.95	7.95	7.95	7.95	7.95	7.95
pH, Final	8.65	8.65	8.8	8.8	8.75	7.53	7.53
Duration of Test (hours)	328	328	328	328	352	352	352
Identifying Variable	Plastic cell; 169 hrs.	Plastic cell; 240 hrs.	H cell; 143 hrs.	H cell; 218 hrs.	75°F; E. coli	95-100°F; E. coli	95-100; Test at 75°; E. coli

TABLE IV (Continued)

Run No.	58	58	58	58
Described in Section	III-A	III-A	III-A	III-A
Peak Anodic Power Density (mw./sq. ft.)	0.7	0.5	0.35	0.25
Peak Total Power Density (mw./sq. ft.)	1.0	0.65	0.45	0.35
Short Circuit Current Density (ma./sq. ft.)	17	13	9	7
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.472	-0.425	-0.475	-0.395
Best Anodic Open-Circuit Potential (volt)	-0.603	-0.603	-0.504	-0.504
pH, Initial	7.63	7.63	7.63	7.63
pH, Final	7.2	7.2	--	--
Duration of Test (hours)	242	242	242	242
Identifying Variable	C. Spor.* 95-100°F; 57 hrs.	C. Spor.* 95-100°F; 127 hrs.	C. Spor.* Rm. Temp; 80 hrs.	C. Spor.* Rm. Temp; 131 hrs.

*Clostridium spirogenes

TABLE IV (Continued)

Run No.	59	59	59	59	59	59
Described in Section	III-B	III-B	III-B	III-B	III-B	III-B
Peak Anodic Power Density (mw./sq. ft.)	0.9	0.85	1.97	1.05	1.4	1.0
Peak Total Power Density (mw./sq. ft.)	1.05	1.12	2.6	1.50	1.85	1.5
Short Circuit Current Density (ma./sq. ft.)	17	17	37	25	30	23
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.590	-0.519	-0.650	-0.505	-0.300	-0.510
Best Anodic Open-Circuit Potential (volt)	-0.685	-0.565	-0.685	-0.565	-0.685	-0.565
pH, Initial	8.52	8.52	8.52	8.52	8.52	8.52
pH, Final	8.9	8.4	8.9	8.4	8.9	8.4
Duration of Test (hours)	288	288	288	288	288	288
Identifying Variable	Helium 104 hrs.	Shaker 107 hrs.	Helium 200 hrs.	Shaker 203 hrs.	Helium 273 hrs.	Shaker 276 hrs.

TABLE IV (Continued)

Run No.	62-I	62-II	62-III	64	64	64
Described in Section	III-E	III-E	III-E	III-G	III-G	III-G
Peak Anodic Power Density (mw./sq. ft.)	0.15	0.15	0.25	0.7	0.25	0.73
Peak Total Power Density (mw./sq. ft.)	0.2	0.2	0.3	1.1	0.5	0.85
Short Circuit Current Density (ma./sq. ft.)	6	6	9	20	6	17
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.365	-0.360	-0.370	-0.555	-0.529	-0.322
Best Anodic Open-Circuit Potential (volt)	-0.530	-0.570	-0.545	-0.600	-0.485	-0.600
pH, Initial	8.3	8.3	8.3	8.0	8.0	8.0
pH, Final	--	--	--	--	--	--
Duration of Test (hours)	138	138	138	286	286	286
Identifying Variable	Repro-ducibility	Repro-ducibility	Repro-ducibility	Small Anode 118 hrs.	Small Cathode 261 hrs.	Small Anode 265 hrs.

TABLE IV (Continued)

Run No.	65	65	65	65
Described in Section	III-D	III-D	III-D	III-D
Peak Anodic Power Density (mw./sq. ft.)	0.4	--	0.25	0.55
Peak Total Power Density (mw./sq. ft.)	0.65	1.3	0.5	0.65
Short Circuit Current Density (ma./sq. ft.)	8	15	9	10
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.530	-0.515	-0.452	-0.450
Best Anodic Open-Circuit Potential (volt)	-0.530	-0.560	-0.575	-0.630
pH, Initial	8.3	8.3	8.3	8.3
pH, Final	9.1	8.5	8.5	8.5
Duration of Test (hours)	130	130	130	130
Identifying Variable	Super-natant H-cell	Plastic Cell	Bubbler above electrode	Bubbler below electrode

TABLE IV (Continued)

Run No.	66	66	66	66	66	66	66
Described in section	III-I	III-I	III-I	III-I	III-I	III-I	III-I
Peak Anodic Power Density (mw./sq. ft.)	--	--	--	--	--	--	--
Short Circuit Current Density (ma./sq. ft.)	--	--	--	--	--	--	--
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	--	--	--	-0.220	+0.130	-0.280	+0.065
Best Anodic Open-Circuit Potential (volt)	-0.580	-0.580	-0.595	-0.220		-0.610	-0.485
pH, Initial	7.1	7.1	7.1	6.4		7.1	7.1
pH, Final	6.1	6.1	6.1	3.6		6.1	6.1
Duration of Test (hours)	444	444	444	444	444	444	444
Identifying Variable	Feces w/o urine; non-sterile; 96 hrs.	Feces w/o urine; non-sterile; 120 hrs.	Cellulase to feces; 192 hrs.	Whatman Paper & Cellulase; 195 hrs.	Whatman Paper & Cellulase; 313 hrs.	Feces + Cellulase; 310 hrs.	Feces - Cellulase transferred; 358 hrs.